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13. ABSTRACT (Maximum 200 words)

The attached report summarizes the results of an AMC study which tests correlation and linear regression analysis as a means to quantify the relationship between AMC resources and U.S. Army materiel readiness. The independent variables chosen were actual obligations of selected AMC procurement and Operations and Maintenance resources; the dependent variables chosen were reported materiel readiness measures. Separate analyses were conducted for each materiel commodity group -- aircraft, missiles, combat vehicles, artillery weapons and armaments, tactical and support vehicles, communications and electronics equipment, and other support equipment. For each commodity group, obligations of each selected resource category were paired with each of the reported readiness measures on a quarterly frequency (first quarter FY81 through fourth quarter FY88) to calculate a coefficient of correlation and a linear regression line. The results, although inconclusive, question the utility of linear regression as a tool for determining the effects of expenditure on materiel readiness.

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Quantifying the Relationship Between

AMC Resources and U.S. Army Materiel Readiness

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25 August 1989

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Enclosures/Figures

QUANTIFYING THE RELATIONSHIP BETWEEN
AMC RESOURCES AND ARMY MATERIEL READINESS

The Program Evaluation Division of the Office of the Deputy Chief of Staff for Program Analysis and Evaluation, HQ AMC, has recently completed a study which tests simple linear regression as a means of quantifying the relationship between AMC resources and Army materiel readiness. An evaluation of the results of that study is presented herein.

1. Background. AMC believes that there is a measurable relationship between its fiscal resources and Army materiel readiness. Qualitatively and intuitively, a relationship between these two elements can be supported. Efforts to quantify this relationship, however, have met with little success despite the importance of readiness as a criterion in Army planning, programing and budgeting decisions. This lack of success can be attributed to a variety of factors; the most prominent is the inability to determine at what point in time a given expenditure for readiness upgrade will actually be manifested through improved readiness in the field. The temporal gap between the two depends upon the complexity of upgrade and the availability of supplies, facilities, services and expertise. Nonetheless, in this period of limited fiscal resources, we are obligated to re-examine the relationship between these elements as a means to justify our resource requirements and maximize readiness with the resources available. A qualitative approach is not sufficient.

2. Scope. We began with an intensive review of prior analyses of the subject area conducted within and outside of the command in order to minimize the chance of an unproductive duplication of effort. Our goal was to develop a quantitative approach toward examining the relationships between selected AMC resources and Army materiel readiness. As measures of resources we chose obligations for procurement and selected OMA accounts; as measures of readiness we chose: fully mission capable (FMC), partially mission capable (PMC), non-mission capable supply (NMCS) and non-mission capable maintenance (NMCM). Enclosures 1 and 2 contain lists of the specific measures chosen. The observed values of these measures for resources and readiness were organized in the following format:

    a. By commodity, as defined by procurement appropriation: (1) Aircraft (APA); (2) Missiles (MIPA); (3) Weapons and Tracked Combat Vehicles, Activity I (WTCV I); (4) Weapons and Tracked Combat Vehicles, Activity II (WTCV II); (5) Other Procurement, Army, Activity I (OPA I); (6) Other Procurement, Army, Activity II (OPA II); (7) Other Procurement, Army, Activity III (OPA III).

b.   For active Army only.

c.   On a quarterly frequency for the period FY77 through FY88, inclusive, or as available; data for years prior to FY77 were scarce.

Our focus on materiel readiness is explained by the fact AMC's resources affect equipment readiness, primarily, as opposed to total unit or force readiness. The latter encompass personnel, training, doctrine, leadership development and force modernization aspects, which must rely on the resources of all Army Major Commands (MACOMs).

3.   Methodology. Our study plan called for the use of correlation and simple linear regression as analytic tools. We chose "AMC resources" as the independent variable and "Army materiel readiness" as the dependent variable. To account for the delayed impact of expenditures on readiness, we included analyses relating resources of a given quarter to readiness levels two, four, six and eight (procurement only) quarters into the future. In addition, we calculated four-quarter moving averages for procurement obligations and, in a separate exercise, used these averages as the independent variable to adjust for the irregular patterns in the rate of obligating funds within the procurement appropriations.

4.   Assumptions.

a.   The observed values of the independent and dependent variables were measured in a consistent manner throughout the study period.

b.   The independent and dependent variables are random variables and form a linear relationship; a bivariate normal distribution with independent, normally distributed random errors.

c.   Procedural changes in readiness reporting over the study period would have insignificant effects on the results of the analysis.

d.   Materiel readiness can be isolated from training, personnel and other forms of readiness.

5.   Data sources.

a.   Readiness data.

We obtained our required materiel readiness data from the "Historical Availability Trends" portion of the Readiness Integrated Data Base (RIDB), furnished by the USAMC Materiel Readiness Support Activity (MRSA). Data consisted of the aggregate percent FMC, PMC, NMCM and NMCS for each

commodity and for each quarter, FY77 through FY88 (exceptions noted below), along with the number of systems reported. The commodity categories defined by the data base were: aircraft (fixed wing), aircraft (rotary wing), missiles, air defense systems, combat vehicles, artillery weapons and armaments, tactical vehicles, electronics equipment and other support equipment. After performing the required arithmetic adjustments, we redefined the commodities to conform to those of the procurement appropriations: aircraft, missiles (including air defense systems), WTCV I (tracked combat vehicles), WTCV II (weapons and other combat vehicles), OPA I (tactical and support vehicles); OPA II (electronics and communications equipment) and OPA III (other support equipment).

  b. Resource data.

   According to our study plan, resource data made available to us should have been in the form of total obligations for direct Army program, by appropriation account/program element and commodity, for each quarter of the period, first quarter FY77 through fourth quarter FY88. The appropriation accounts originally chosen were procurement (end items, secondary items and modifications), operations and maintenance (selected program elements), Army Stock (ASF) and Army Industrial Fund (AIF). What we were able to obtain, however, fell short of requirements. With the exception of particular program elements identified below, usable OMA data, available for the period 1st quarter FY81 through 4th quarter FY88 only, were extracted from the DARCOM (now AMC) Resource Management reports 159 and 218. For PE 732207, Depot Maintenance Activities, the data were extracted from the DESCOM Resource Management report 984 for the same period. Insufficient data precluded analysis of the OMA PEs Total Package Fielding and Life Cycle Software Engineering and the accounts Army Stock Fund and Army Industrial Fund. All procurement data were extracted from automated records provided by USAFAC (US Army Finance and Accounting Center) and covered the period 4th quarter FY82 through 4th quarter FY88.

  c. Data voids and treatments.

   (1) Available readiness data for aircraft began with the fourth quarter FY83 and for missiles, first quarter FY81; the analyses of these two commodities began with the same quarters.

   (2) Procurement data for WTCV modifications were not delineated by activity (WTCV I, WTCV II). As a result, the analysis for modifications was limited to the aircraft and missile commodities; our study plan excluded OPA I, OPA II and OPA III modifications because of the small percentage of total activity expenditure which they represent.

(3)   Obligation data by commodity were available for the procurement appropriations and for PEs 728009 (First Destination Transportation) and 732207 (Depot Maintenance Activities). Obligation data by MSC were available for all accounts under analysis. To estimate obligations by commodity for the remaining OMA PEs, we applied the percentage distribution, by commodity, of each MSC's procurement obligations to the totality of its obligations for each applicable OMA PE. This calculation resulted in an estimated percentage distribution, by commodity, of the obligations for each OMA PE of each MSC. For each PE, we then totaled the estimated obligations, by commodity, of each MSC.

(4)   Resource data were expressed in FY88 constant dollars.

6. Analyses.

a. Our analyses followed the methodology of the study plan except where hampered by insufficient data. For each account (OMA PE, procurement category), we paired fiscal resources, by commodity, with each set of reported readiness measures: FMC, PMC (aircraft only), NMCS and NMCM (OMA only). We calculated coefficients of correlation and performed simple linear regression analysis. The regression analysis permitted us to determine "significance" of correlation by examining the slope of the resulting linear regression line.

b. We paired independent and dependent variables by assuming (1) that readiness is affected by expenditure at the time dollars are obligated or (2) that the impact of a given expenditure upon readiness will not occur until some future date. Several such "future dates" were analyzed. For each of the OMA PEs, we performed analyses based upon a no-, two-, four- and six-quarter delay between expenditure and effect. For the procurement categories, we chose four- six- and eight-quarter delays. In addition, we calculated four-quarter moving averages for procurement resource variables to adjust for the "seasonal" nature of procurement obligations.

c. For paired relationships with a coefficient of correlation greater than or equal to .3 (or less than or equal to -.3), we conducted tests of statistical significance: a rho-test on the coefficient of correlation within a 95 percent confidence interval and a t-test on the slope of the line at a 5 percent significance level. All paired relationships which showed a coefficient of correlation greater than or equal to .3 (or less than or equal to -.3) and which passed the two aforementioned statistical tests were identified as usable in confirming the hypothesis that a linear relationship between AMC resources and Army materiel readiness exists.

4

7. Findings and lessons learned. The charts at enclosure 3 summarize the results of the linear regression analyses.

a. The correlation and linear regression analyses yielded few significant relationships between AMC resources and Army materiel readiness. This general lack of linear association cannot be construed as proof that there is no quantitative relationship between the two variables. We may assume only that linear regression may not be the appropriate analytic tool for determining the characteristics of such a relationship. Several of the analyses, especially those applicable to aircraft and WTCV II, yielded significant linear relationships but with slope of line in the unexpected direction; i.e. FMC/PMC correlated negatively while NMCS/NMCM correlated positively with obligations. Such anomalous results do not lend support to a hypothesis that lower expenditures might lead to higher readiness rates.

b. The analyses of delayed affects of expenditure upon readiness produced results far below expectations. We know that money spent affects readiness of systems well beyond the date of actual expenditure. Although such analyses yielded some relatively high coefficients of correlation, the rho tests on many of these coefficients failed. Rho is a function of the coefficient of correlation and of the number of data pairs used for its calculation. As we chose increasing periods of delay between expenditure and readiness, the number of data pairs at our disposal decreased. A delay period of eight quarters, the most logical choice for procurement, had the greatest failure rates when subjected to the statistical tests merely because of the reduced number of data pairs. Analyses of valid delay periods such as four or five years were totally dismissed because of limited data.

c. Army materiel readiness measures were nearly "flat," (exhibited little variance) during the years under study, as shown by the descriptive statistics for FMC rates in the table below.

REPORTED FULLY MISSION CAPABLE RATES

COMMODITY	AVG	STD DEV	MIN	MAX
AIRCRAFT	72.4	1.9	69.1	76.2
MISSILES	95.6	.7	93.6	97.0
WTCV I	90.1	1.4	86.7	92.4
WTCV II	94.1	1.0	92.5	96.6
OPA I	89.5	1.8	87.0	92.4
OPA II	92.8	1.7	90.4	95.5
OPA III	91.9	2.5	81.3	94.2

d. We have the ability to normalize dollar resources throughout any given time period by applying inflation indices. However, we have no scheme for normalizing Army materiel readiness measures with respect to system technological complexity and capability. Generally, it costs more to bring a highly advanced system up to a given level of readiness than it does to bring its less technologically complex predecessor up to that same level. Hence, we should at times expect decreasing readiness levels with increasing resource output and accept such a phenomenon as positive provided that capability is on the rise as well. However, acceptance of this condition implies abandonment of linear regression analysis.

e. AMC historical funding data sources are structured to support finance and accounting functions not management studies of the type discussed herein. Moreover, these data sources are documented in a variety of reports scattered throughout several Separate Reporting Activities (SRAs). Existing historical funding data are ineffective in capturing information by commodity category, system, appropriation, appropriation subcategory (e.g., procurement of secondary items, modifications), program element, and PE point account. HQ, AMC does not have an office whose mission includes the retention of data in a format usable for operations research analysis or for other forms of analyses required by those who contribute to management decisions.

f. Certain OMA functions; e.g., Total Package Fielding, have changed associated program element or PE point account. We need a crosswalk which maps the changing PEs of specified functions.

8. Recommendations. The above findings lead to the recommendation that no further historical quantitative analysis of AMC resources and Army materiel readiness be pursued until we develop an AMC resource data base suitable for functional and management analysis. Specific recommendations include:

a. Identify an AMC central repository for the identification, collection, categorization and retention of all AMC resource data (historical, current and projected). Ensure that data are delineated according to categories required for analysis and that adequate crosswalks are available for the identification of changing programs elements of specified functions. All data should be retained for future analytic studies until a formal review by experts of all functional areas determines that portions may be discarded.

b. Develop and/or apply alternative measures of readiness; e.g., operational availability (Ao). Measures applied should have the following attributes:

(1) Be quantifiable.

    (2) Be objective, free from biases.

    (3) Be standardized with respect to commodities,
         systems and Army components.

    (4) Account for changes in system capabilities
         or complexities.

    (5) Permit quantifiable linkages between materiel
         readiness, AMC resources and general performance
         measures.

    c. Explore alternative analytic methods. An example is
the ongoing USAMSAA (US Army Materiel Systems Analysis
Agency) study which relates operating and support (O&S) costs
of retail/wholesale parts to operational availability.
Mathematical modeling and simulation techniques could be
pursued but they will, like the linear regression approach
presented herein, be highly constrained by the availability
of resource data.

9. Summary. Initiatives to relate AMC's resources to Army
materiel readiness through qualitative analysis have
consistently born positive results. However, until we change
our process of documentation of historical resource data,
until we develop readiness measures which account for
enhancement of system capability and until we develop a
credible methodology for determining the delayed effects of
expenditure upon readiness, any attempt to relate the two
variables through quantitative means will yield inconclusive
results.

AMA RESOURCES

GLOSSARY

LEVEL 1
    PA — PROCUREMENT, ARMY
   ASF — ARMY STOCK FUND
   AIF — ARMY INDUSTRIAL FUND
  RDTE — RESEARCH DEVELOPMENT AND TEST AND EVALUATION
   MCA — MILITARY CONSTRUCTION, ARMY
   OMA — OPERATIONS AND MAINTENANCE, ARMY
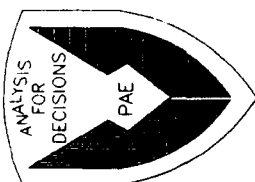
LEVEL 2
  AMMO — AMMUNITION PROCUREMENT ACTIVITIES
   APA — AIRCRAFT PROCUREMENT ACTIVITIES
   MSL — MISSILE PROCUREMENT ACTIVITES
  WTCV — WEAPONS AND TRACKED COMBAT VEHICLE PROCUREMENT
         ACTIVITIES
   OPA — OTHER PROCUREMENT ACTIVITIES

   6.1 — BASIC RESEARCH
   6.2 — EXPLORATORY DEVELOPMENT
  6.3a — ADVANCED DEVELOPMENT, PROOF OF PRINCIPLE DEMO
  6.3b — ADVANCED DEVELOPMENT, EXPLORATORY DEVELOPMENT
   6.4 — ENGINEERING DEVELOPMENT
   6.5 — MANAGEMENT AND SUPPORT
   6.7 — OPERATIONAL SYSTEM DEVELOPMENT

    P2 — GENERAL PURPOSE FORCES
    P3 — INTELIGENCE AND COMMUNICATIONS
    P7 — SUPPLY AND MAINTENANCE
    P8 — TRAINING, MEDICAL AND OTHER PERSONNEL ACTIVITIES
    P9 — ADMINISTRATIVE AND ASSOCIATED ACTIVITIES
   P10 — SUPPORT OF OTHER NATIONS
   P11 — BASE OPERATIONS
   P12 — REAL PROPERTY MAINTENANCE ACTIVITIES

LEVEL 3
   TCV — TRACKED COMBAT VEHICLES
  WOVC — WEAPONS AND OTHER COMBAT VEHICLES
   TSV — TACTICAL SUPPORT VEHICLES
    CE — COMMUNICATIONS AND ELECTRONIC EQUIPMENT
   OSE — OTHER SUPPORT EQUIPMENT

  LCSE — LIFE CYCLE SYSTEMS ENGINEERING
   TPF — TOTAL PACKAGE FIELDING

LEVEL 3   SDO — SUPPLY AND DEPOT OPERATIONS
CONTINUED   SMO — SUPPLY MANAGEMENT OPERATIONS
             CPA — CENTRAL PROCUREMENT ACTIONS
             FDT — FIRST DESTINATION TRANSPORTATION
             SDT — SECOND DESTINATION TRANSPORTATION
              DM — DEPOT MAINTENANCE
             MSA — MAINTENANCE SUPPORT ACTIVITIES
             NET — NEW EQUIPMENT TRAINING
             NEP — NEW EQUIPMENT PUBLICATIONS
             PAY — CIVILIAN (DIRECT AND INDIRECT HIRE)

LEVEL 4   END — END ITEMS
             PBS — PRODUCTION BASE SUPPORT
             MOD — MODIFICATION
             SEC — SECONDARY ITEMS

             LAO — LOGISTICS ASSISTANCE OFFICE
             AIF — ARMY INDUSTRIAL FUND

READINESS MEASURING CRITERIA HIERARCHY

UNIT READINESS

LEVEL

1

PER   TNG   EMC   EOH   ER   2

GND   AC   MSL   3

NMC   FMC   NMC   FMC   PMC   NMC   FMC   4

NMCS   NMCM   NMCS   NMCM   NMCS   NMCM   NOREP   5

——— VARIABLES OF INTEREST
——— VARIABLES NOT EXAMINED
······ INSUFFICIENT DATA TO CONDUCT STUDY

NOTES (BY LEVEL):

2 – Materiel readiness examined (Training & Personnel omitted).

3 – Missile equipment reporting treated as ground equipment reporting (Units not penalized for NOREP time).

4 – The Equipment Materiel Condition Code of primary intrest is Fully Mission Capable.

GLOSSARY

LEVEL 2   PER — PERSONNEL STATUS
                TNG — TRAINING STATUS
                EMC — EQUIPMENT MISSION CAPABLE
                EOH — EQUIPMENT ONHAND
                ER — EQUIPMENT READINESS

LEVEL 3   GND — GROUND EQUIPMENT
                AC — AIRCRAFT
                MSL — MISSILES

LEVEL 4   NMC — NONMISSION CAPABLE
                FMC — EQUIPMENT: FULLY MISSION CAPABLE
                PMC — EQUIPMENT: PARTIALLY MISSION CAPABLE
          NOREP — NON—REPORTED TIME

LEVEL 5   NMCS — NONMISSION CAPABLE FOR SUPPLY
           NMCM — NONMISSION CAPABLE FOR MAINTENANCE

ANALYSIS RESULTS--GROUP DEFINITIONS:

GROUP I

Q TEST SHOWS RELATIONSHIP

T TEST SHOWS SIGNIFICANCE

SLOPE OF LINE IN UNDERLINED EXPECTED DIRECTION

GROUP I SUBCATEGORY

ALL STATISTICAL RELATIONSHIPS
ARE GOOD HOWEVER,

REPORTED READINESS IS ALREADY
ABOVE PUBLISHED DA GOALS.

●

GROUP II

Q TEST SHOWS RELATIONSHIP

T TEST SHOWS SIGNIFICANCE

SLOPE OF LINE IN UNEXPECTED DIRECTION

GROUP III

ALL OTHER CASES

ANALYSIS RESULTS:

FIRST DESTINATION TRANSPORTATION

PE 728009
COMPLETE RESULTS

SECOND DESTINATION TRANSPORTATION

PE 728010
COMPLETE RESULTS

ANALYSIS RESULTS:

SUPPLY MANAGEMENT OPERATIONS
PE 72112
COMPLETE RESULTS

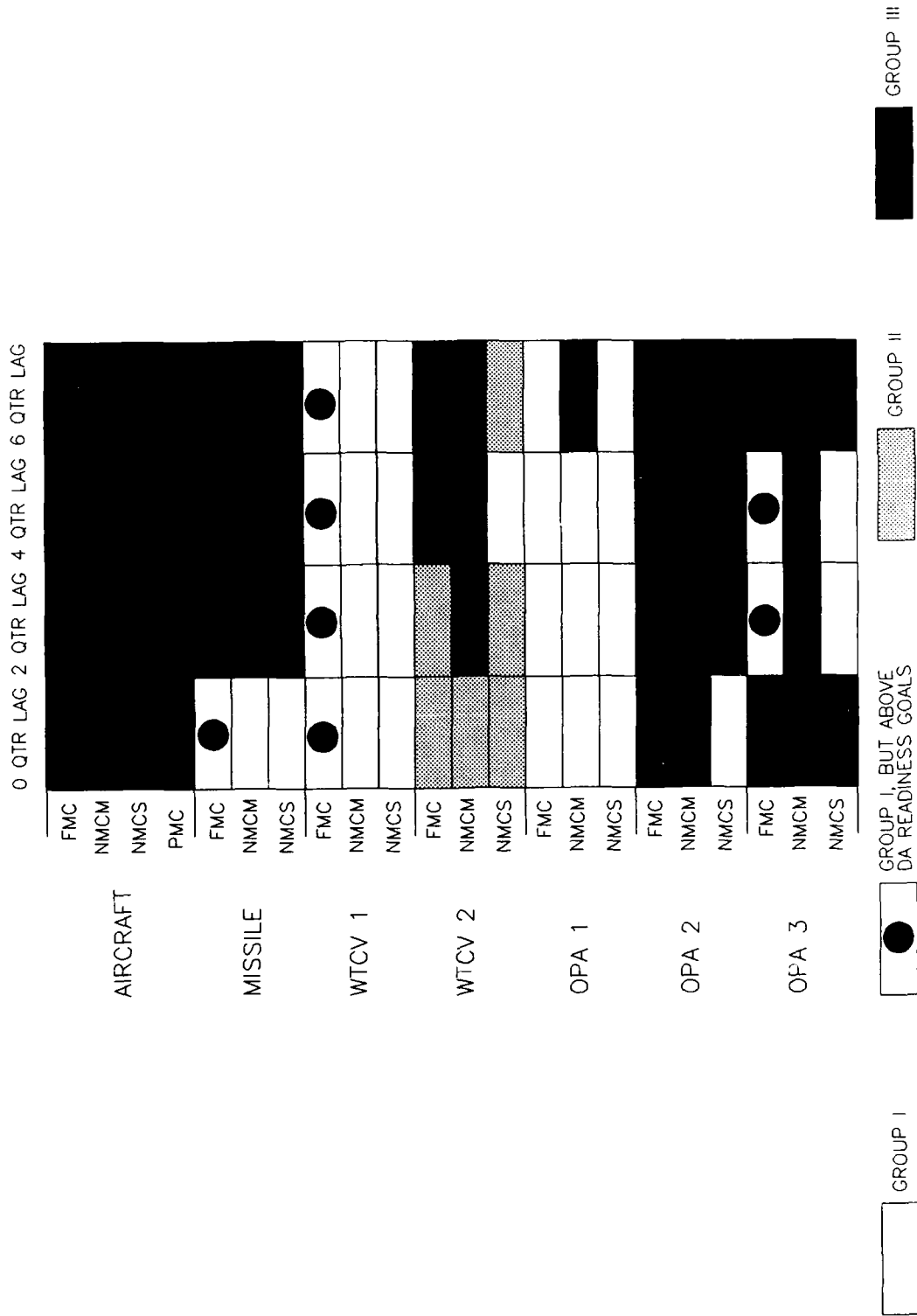## SUPPLY DEPOT OPERATIONS
PE 72111
COMPLETE RESULTS
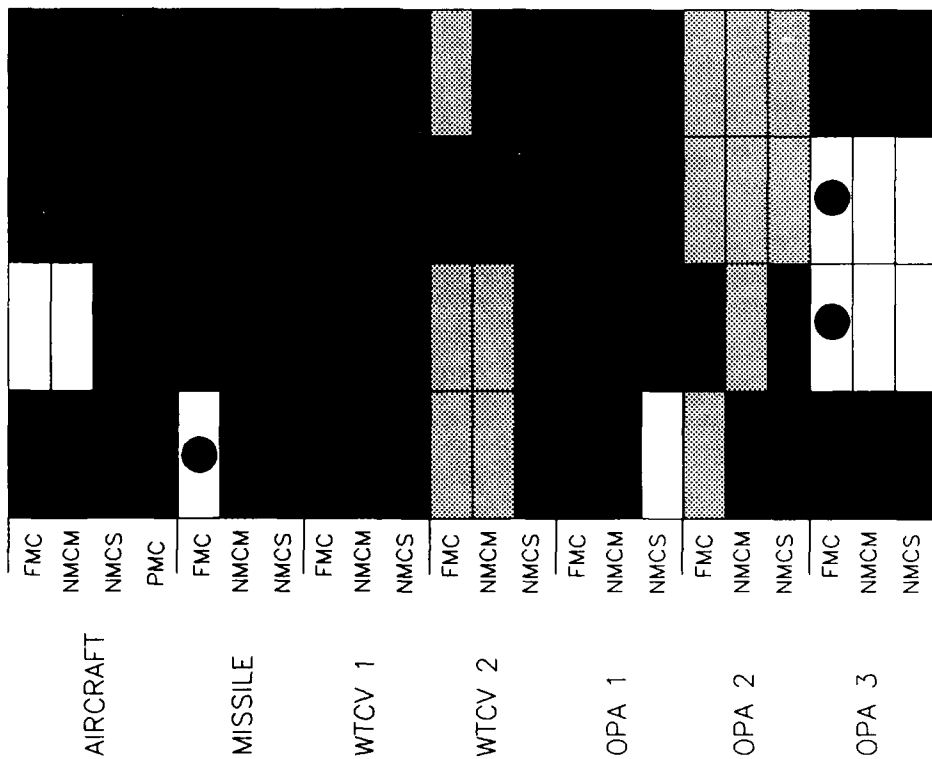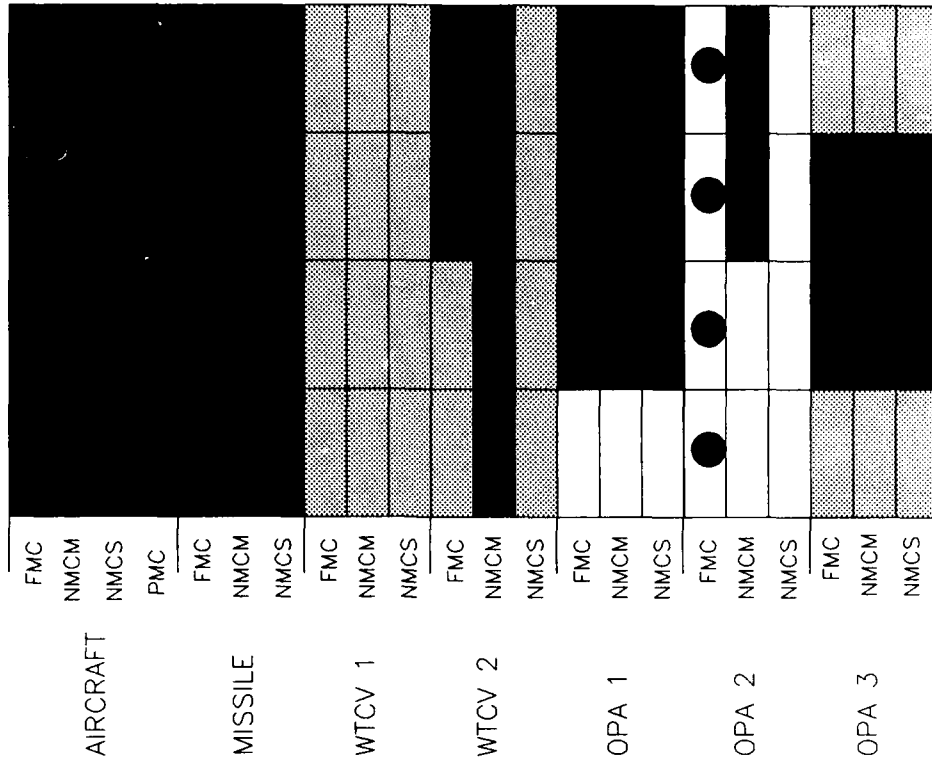
ANALYSIS RESULTS:
CENTRAL PROCUREMENT ACTIVITIES
PE 721113
COMPLETE RESULTS
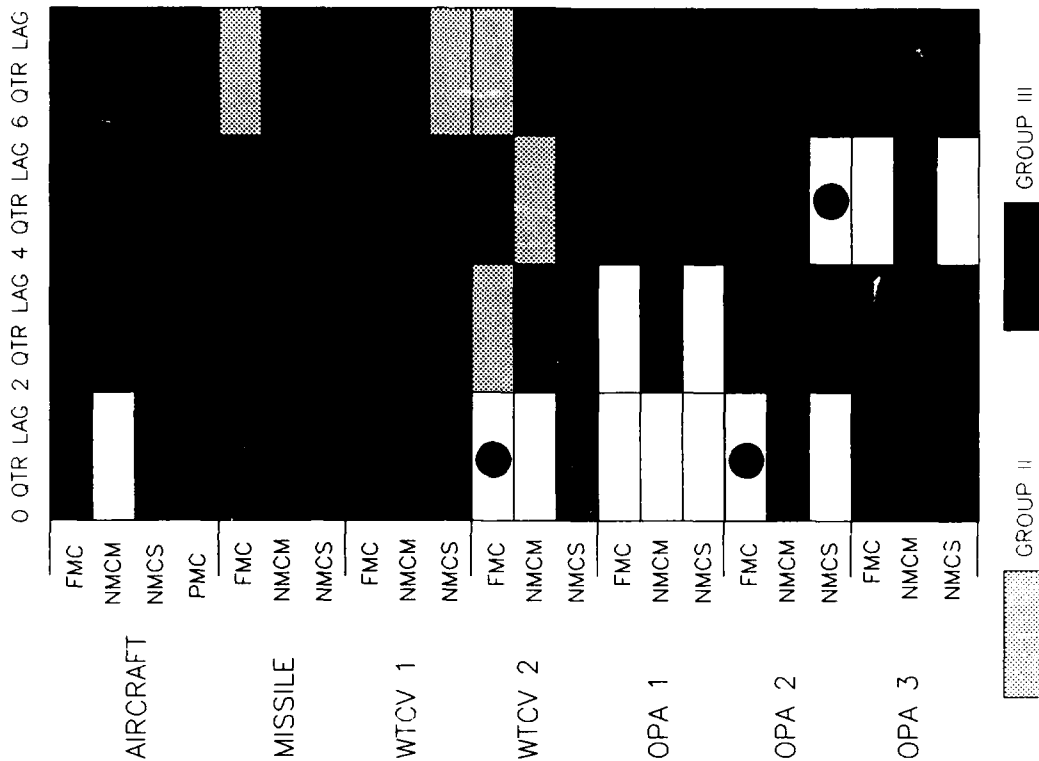
ANALYSIS RESULTS:

DEPOT MAINTENANCE ACTIVITIES
PE 732207
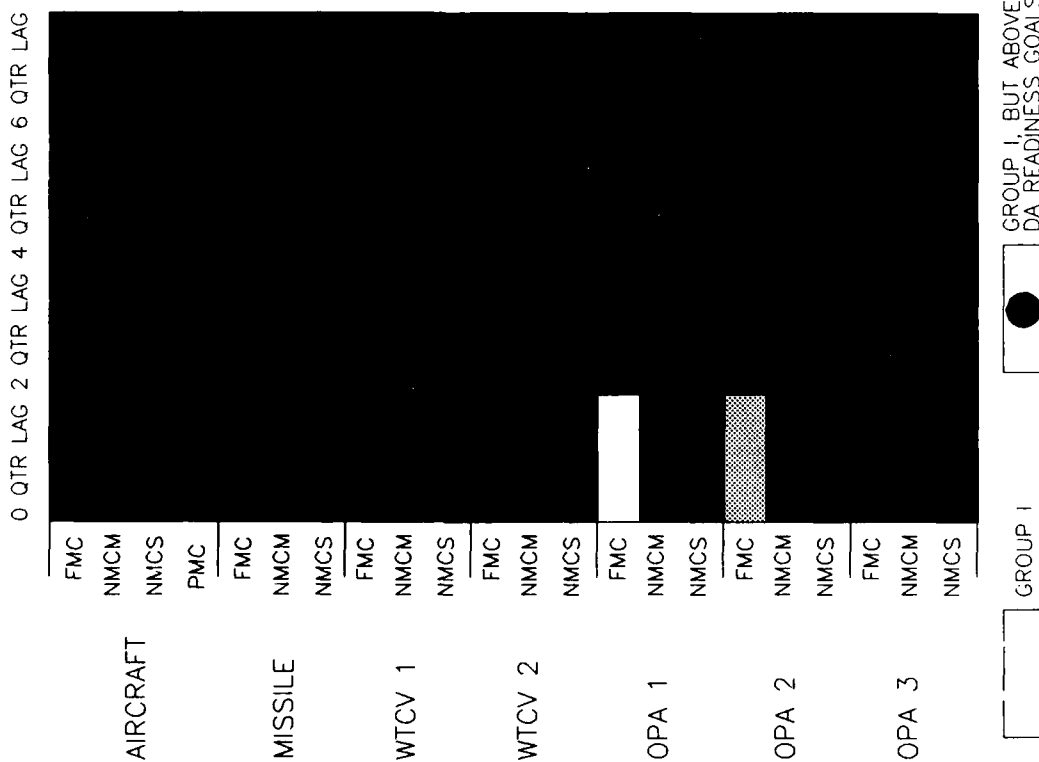#### COMPLETE RESULTS

TOTAL MAINTENANCE SUPPORT ACTIVITIES
PE 738017
COMPLETE RESULTS

ANALYSIS RESULTS:
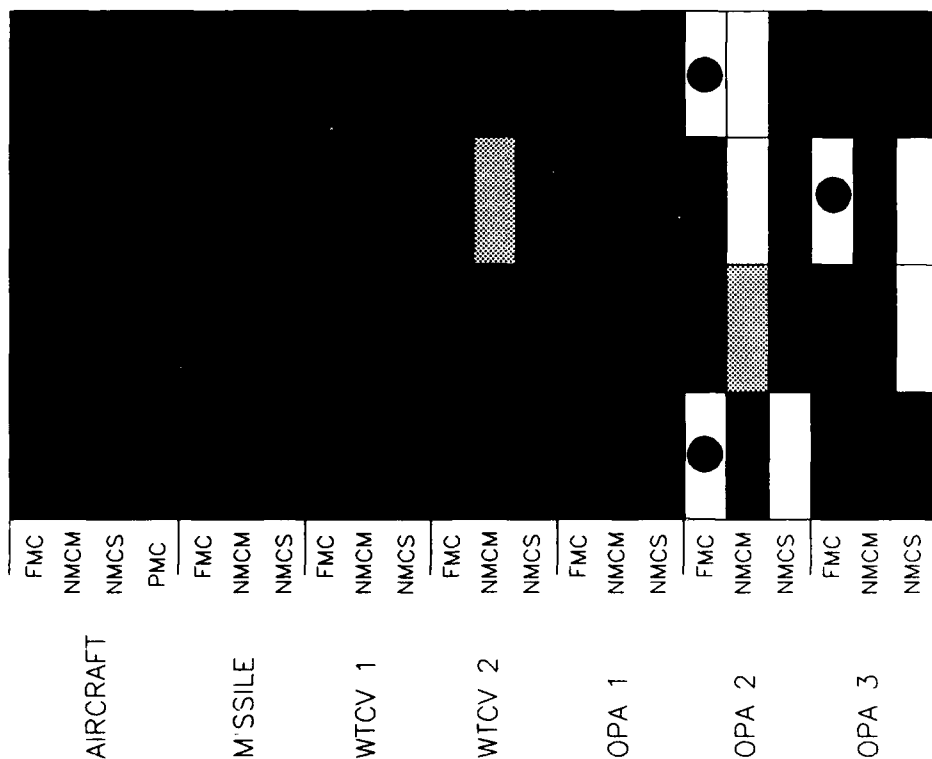
ORGANIZATIONAL NET
PE 738017.S
COMPLETE RESULTS

NEW EQUIPMENT PUBLICATIONS:
PE 738017.R
COMPLETE RESULTS

ANALYSIS RESULTS:

MOVING AVERAGE

PROCUREMENT, SECONDARY ITEMS
COMPLETE RESULTS

		4 QTR LAG	6 QTR LAG	8 QTR LAG
AIRCRAFT	FMC			
	NMCM	N/A	N/A	N/A
	NMCS			
	PMC	N/A	N/A	N/A
MISSILE	FMC			
	NMCM	N/A	N/A	N/A
	NMCS			
WTCV 1	FMC			
	NMCM	N/A	N/A	N/A
	NMCS			
WTCV 2	FMC			
	NMCM	N/A	N/A	N/A
	NMCS			
OPA 1	FMC			
	NMCM	N/A	N/A	N/A
	NMCS			
OPA 2	FMC	●	●	●
	NMCM	N/A	N/A	N/A
	NMCS			
OPA 3	FMC			
	NMCM	N/A	N/A	N/A
	NMCS			

PROCUREMENT, END ITEMS
COMPLETE RESULTS

		4 QTR LAG	6 QTR LAG	8 QTR LAG
AIRCRAFT	FMC			
	NMCM	N/A	N/A	N/A
	NMCS			
	PMC	N/A	N/A	N/A
MISSILE	FMC			●
	NMCM	N/A	N/A	N/A
	NMCS			
WTCV 1	FMC			
	NMCM	N/A	N/A	N/A
	NMCS			
WTCV 2	FMC			
	NMCM	N/A	N/A	N/A
	NMCS			
OPA 1	FMC			
	NMCM	N/A	N/A	N/A
	NMCS			
OPA 2	FMC	●	●	●
	NMCM	N/A	N/A	N/A
	NMCS			
OPA 3	FMC	●		
	NMCM	N/A	N/A	N/A
	NMCS			

Legend:

GROUP I

GROUP I, BUT ABOVE DA READINESS GOALS ●

GROUP II

GROUP III

MOVING AVERAGE

3-7

ANALYSIS RESULTS:

PROCUREMENT, SECONDARY ITEMS
COMPLETE RESULTS

PROCUREMENT, END ITEMS
EMERGING RESULTS

PROCUREMENT, SECONDARY ITEMS — COMPLETE RESULTS

	4 QTR LAG	6 QTR LAG	8 QTR LAG
AIRCRAFT FMC			
NMCM	N/A	N/A	N/A
NMCS	N/A	N/A	N/A
PMC	N/A		
MISSILE FMC			
NMCM	N/A	N/A	N/A
NMCS			
WTCV 1 FMC			
NMCM	N/A	N/A	N/A
NMCS			
WTCV 2 FMC			
NMCM	N/A	N/A	N/A
NMCS			
OPA 1 FMC			
NMCM	N/A	N/A	N/A
NMCS			
OPA 2 FMC			
NMCM	N/A	N/A	N/A
NMCS			
OPA 3 FMC			
NMCM	N/A	N/A	N/A
NMCS			

GROUP I

GROUP I, BUT ABOVE DA READINESS GOALS

PROCUREMENT, END ITEMS — EMERGING RESULTS

	4 QTR LAG	6 QTR LAG	8 QTR LAG
AIRCRAFT FMC			
NMCM	N/A	N/A	N/A
NMCS	N/A	N/A	N/A
PMC	N/A	N/A	N/A
MISSILE FMC			
NMCM	N/A	N/A	N/A
NMCS			
WTCV 1 FMC			
NMCM	N/A	N/A	N/A
NMCS			
WTCV 2 FMC			
NMCM	N/A	N/A	N/A
NMCS			
OPA 1 FMC			
NMCM	N/A	N/A	N/A
NMCS			
OPA 2 FMC			
NMCM	N/A	N/A	N/A
NMCS			
OPA 3 FMC			
NMCM	N/A	N/A	N/A
NMCS			

GROUP II

GROUP III

ANALYSIS RESULTS:

MOVING AVERAGE

PROCUREMENT, SYSTEM MODIFICATIONS
COMPLETE RESULTS

PROCUREMENT, SYSTEM MODIFICATIONS
COMPLETE RESULTS

RAW DATA